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COST AND SCHEDULE MANAGEMENT ON THE QUIET SHORT-HAUL RESEARCH AIRCRAFT PROJECT

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SUMMARY

The Quiet Short-Haul Research Aircraft (QSRA) Project, one of the largest aeronautical programs undertaken by NASA to date, achieved a significant cost underrun. This is attributed to numerous factors, not the least of which were the contractual arrangement and the system of cost and schedule management employed by the contractor. This paper summarizes that system and the methods used for cost/performance measurement by the contractor and by the NASA project management. Recommendations are made for the use of some of these concepts for future programs of a similar nature.

INTRODUCTION

The QSRA is a flight research facility to be used by the government to develop design criteria and airworthiness standards for quiet, propulsive-lift transports. The research application of the aircraft is focused on takeoff and landing and other terminal-area operations associated with the propulsive-lift mode of flight. The most important priorities for the program were safety, cost, and research capability, in that order. Consequently, the general approach for the aircraft design effort was to "design to cost," with emphasis on minimizing absolute cost and/or maximizing research capability per dollar, but with no compromises in flight safety.

In February 1976, the Boeing Commercial Airplane Company was selected by NASA to design and build the Quiet Short-Haul Research Aircraft (QSRA). The source selection process included a competitive negotiation between Boeing and one other major contractor. The Boeing contract was negotiated first. During negotiations substantial reductions were made in engineering and manufacturing man-hours. Commensurate work statement reductions were made in some, but by no means in all areas. At the same time, Boeing proposed a cost-share-award-fee type contract wherein the contractor shared \$1,200,000, or approximately 6% of the \$20 million initial contract cost. The contractor was also to receive an award fee, based on performance, which, at the discretion of the government, could range from 0 to 5% of government target cost. There was no base fee. In addition, the contractor offered to share 50% of any overrun, up to a maximum overrun share of \$2 million for a potential share of \$3,200,000. Thus, in addition to the stated NASA priority of low cost, there was a strong financial incentive for the contractor to remain within and perform under the budget. The Boeing project

team responded to this challenge with a strong technical and management performance which resulted in delivery of the airplane one month ahead of schedule and \$2.6 million (12%) under target cost, and which earned the contractor 100% of the available award fee for each of the six award fee periods through aircraft delivery.

There are many factors, both technical and economic, which contributed to the underrun on the QSRA contract. These will be discussed in more detail in a subsequent paper. Some may be unique to this program. One factor not unique to this program, however, is the program control method employed. Indications of favorable cost performance were apparent early in the program. Several design trade-offs resulting in improved producibility were developed in the early stages of the program. Also, many engineering and manufacturing activities were on or ahead of schedule and on or below budget. This performance was reinforced through the NASA project management approach to defer contract additions, whenever possible, until funding availability within the original budget was assured by realization of the anticipated underrun.

The purpose of this paper is to document the cost and schedule control and cost/performance measurement techniques used on the QSRA project in the hope that they may prove useful on future programs of a similar nature.

PROGRAM COST AND SCHEDULE CONTROL

The objective of a program control system is to provide cost and schedule performance visibility in a timely fashion to both contractor and government functional managers and to senior management personnel in order to ensure project completion within the budget. The system should permit early detection of problems and accurate assessment of their impact. It should support frequent and up-to-date status reporting and management review for decision making purposes. *It is highly desirable that the system produce a common set of cost reports for review by both contractor and government personnel.* This facilitates communication and minimizes the nonproductive effort that often goes into report generation as well as the errors introduced in most cost data manipulations.

Boeing used established in-house program control systems for the QSRA. Existing systems were adapted for work authorization, budgeting, scheduling, cost accumulation, performance measurement and reporting. Schedules and budgets were established at level 2, 3, and 4 (major activities only) of the work breakdown structure (WBS) shown in figure 1. *The functional manager assigned to each WBS element was responsible for cost and schedule performance as well as technical achievement.* Work authorizations were used to assign manpower and schedules for each job assignment, with charge numbers traceable to each WBS element, organization, and cost element.

The program director controlled the total budget, allocating task budgets to each functional manager at 90% of the contract target cost;

this established a 10% initial management reserve. The program director then used the reserve to adjust budgets for things outside the functional managers' control, such as overhead rate changes, internal work statement growth, labor rate increases, and schedule changes.

Boeing employed a "dynamic" budget concept for the QSRA. Contract target cost increases for external work statement growth were allocated among the appropriate WBS elements and the management reserve. Budget transfers between the management reserve and other WBS accounts or inter-WBS transfers were made for work package refinements or for the reasons discussed above. All changes required concurrence of the program director and immediate notification to NASA of the reasons.

Although arguments are often made against it there are valid reasons for permitting the budget baseline to change on a program like QSRA. A budget which reflects design changes, overhead rate changes, etc., is more realistic; hence, it sustains the motivation and concern of functional managers far better than one which is hopelessly obsolete. It also provides a more accurate cost picture to project management within the company and the government, and facilitates realistic estimates of cost at completion, earned value, etc. There are disadvantages as well. A changing budget baseline requires considerable effort to maintain. Unless closely controlled, it could be used to hide performance problems. For this reason it is sometimes called a "rubber budget" (ref. 1). Nevertheless, the project management at Boeing and NASA agreed that for a closely knit organization such as existed for QSRA, the advantages of rebudgeting outweighed the disadvantages. The excellent communication between Boeing and NASA counterparts was a key factor in that decision. Also, the general underrun condition early in the contract helped considerably.

Actual costs were accumulated through an automated system with tracking by cost element, by WBS, and by organization. This system provided reports by WBS of labor costs on a weekly basis, and a monthly comparison of actual costs (labor and nonlabor) with budgets. Estimates at completion were prepared quarterly by each functional manager to provide the basis for higher management action.

Schedules were established for each WBS element. Significant milestone events were identified for activities to which individual budgets were assigned. Within engineering, the milestones included significant tests, analyses required in support of design, or design release items for which release dates mutually acceptable to engineering and manufacturing had been established. Within manufacturing, milestones included completion of major components or assemblies.

Cost and schedule information was displayed on a common grid for each WBS and posted on the walls of a program control room. The common grid was very useful in providing visual cost/schedule "integration." The control room also served as the location for biweekly program review meetings, where management and other key personnel reviewed cost, schedule, and technical performance.

CONTRACTOR REPORTING

The contract specified that monthly financial reports should include NASA Form 533M and 533P (ref. 2), or the contractor's equivalent system, for each WBS element. NASA Form 533Q reports were required quarterly. The level of detail for each WBS element was left to negotiation.

The computerized cost management system used by Boeing Commercial Airplane Co. - Engineering Division for research contracts reported cost by WBS element, cost element, and functional organization. It readily lends itself to generation of the 533M and 533Q reports. Therefore, these reports were submitted for all level 3 WBS elements, and at level 4 for high cost items such as wing box, wing trailing edge, and major systems.

The system does not as easily support the generation of the 533P since the basic data elements, planned value of work accomplished and percent completion, are not able to be derived from the computerized cost management system without special input and reprogramming. It seemed nonproductive to require submission of the 533P at level 3 of the WBS for several reasons. First, the estimates of planned value of completed work would be quite subjective and therefore of questionable validity. Second, Boeing would not rely on this information for cost control, and cost visibility to NASA would not be significantly enhanced over that available from the alternate financial reports received in lieu of 533P. Finally, it would be costly to prepare because the contractor would have to assign both direct and overhead personnel to generate level 4 supporting data and reports. Therefore, the 533P was required only at level 2 of the QSRA WBS.

The time lag usually present in cost reporting makes problems late in surfacing. Since the objective of the government project office is to help prevent an overrun rather than just do a good job of tracking one, it was judged most useful for NASA to obtain reports which were compatible with the Boeing cost control system. These could then be updated in the interim period by the resident manager in his weekly reports in order to provide near real-time cost monitoring. The expense of preparing the monthly report would be only that of duplicating existing data rather than generating new data. Most important, the information available from the Boeing internal system appeared to meet NASA's needs for cost surveillance very well.

The monthly reports ultimately provided for each WBS level are shown in figure 2. The information which proved to be most useful in tracking progress, identifying potential cost or schedule problems, and assessing program impact is that listed as "533P equivalent." These reports were a combination of graphical and tabular data, which permitted a rapid assessment of *trends* as well as absolute cost values at any point in time. If a cost growth problem developed, these charts also permitted identification of the cause, which might be due to schedule slippages, labor rates, manloading variations, material usage, or other factors. Examples of these reports are discussed below.

Figure 3 illustrates the milestone schedule for the wing trailing edge, a level 4 WBS element. Status is shown as of February 28, 1977 (12 mo after contract go-ahead) for this and the following figures. The schedule relates design, analysis, and manufacturing milestones to the major milestones of the program, and identifies specific events which are readily monitored. It also shows that the 25% drawing release point was reached 6 wk ahead of schedule, while rib fabrication was started 10 wk early. This chart was updated biweekly in the Boeing control room and submitted to NASA monthly.

The engineering release status for the wing trailing edge is shown in figure 4. This chart was updated weekly. It compares the actual number of releases to the number committed in joint negotiations with manufacturing personnel. These consisted of both drawings and advance material releases, and it is important that both be on schedule since material must be ordered and the manufacturing manload and machine tool usage must be scheduled. The chart gives a good indication of the progress of the design effort and also suggests that the manufacturing planning activity should be progressing satisfactorily, since there were 12 releases ahead of schedule and (equally important) none behind at that time.

Figure 5 measures manufacturing labor progress. It compares cumulative actual manufacturing man-hours to the budgeted hours for this WBS element. It also shows the "earned" value, which is the estimated, or shop budget man-hours for work completed. There was no partial credit earned for work started but not yet completed nor for an allocatable portion of the management reserve, so the reported earned value was conservative. This is very important. Many earned value systems give 50% credit when work is started, thus creating an erroneous impression that progress is greater than it really is, and hiding cost problems for an extended period of time.

In addition to the three measures of schedule/functional performance, there were two important measures of cost reported for each WBS element. One, shown in figure 6, was manloading. Budgeted and actual manpower levels in engineering and operations (manufacturing and test support) were reported weekly. This report provided a check on cost and schedule performance in two ways: 1) early indications of technical problems are often evident in manloading deviations from plan; 2) excessive manpower levels, or failure to off-load personnel upon task completion, will quickly affect cost performance but would be reflected in the weekly manpower reports earlier than in the monthly cost reports. In this case, the schedule acceleration reported in figures 3, 4, and 5 was achieved even though engineering and operations manpower levels were under budget, a happy situation indeed!

The most important financial data to monitor for each WBS element is the comparison of actual and budgeted costs relative to scheduled event completion. Figure 7 illustrates that cumulative actual cost for the wing trailing edge was modestly below budget although the engineering and manufacturing effort was ahead of schedule. Moreover, the manager's estimate at completion (MEAC) was projecting a budget underrun of $82 thousand (8%)

through the conclusion of effort on that WBS element. It should be remembered that the budget value on this chart is less than the contract value by the amount of the management reserve (10%) extracted at contract go-ahead by Boeing's program director. By the end of the program the budget on this WBSE was underrun by a substantial amount.

If cost problems had developed, additional visibility was available through the variance report shown at the left of figure 7. This itemized the cost variance by cost element in order to pinpoint the source of the problem. The analysis was made whenever a WBS element exceeded its budget by 10%.

COST/PERFORMANCE MEASUREMENT

Cost/performance measurement on the QSRA contract was made on a *weekly* basis. The internal cost management system provided weekly output of assigned manpower and total labor charges by WBS element. The respective control room charts were updated weekly and the data was made available to the NASA resident manager for his weekly report to project management at Ames. Thus, both the contractor and the government received a weekly comparison of actual cost vs budget. Other data received weekly were current actual and cumulative average labor rates by functional organization (design, technology, manufacturing), additions or reductions in management reserve, and a comparison of actual vs scheduled engineering releases. These were carefully monitored for signs of trouble.

In addition to having Boeing cost and schedule reports, the NASA resident manager attended weekly staff meetings held by the program manager and the design, technology, and manufacturing groups. He also made daily visits to all areas of the plant where QSRA work was in progress. This was very important for it provided an independent assessment of schedule progress vs cost accumulation. The value of this "informal" cost/performance measurement can hardly be overemphasized. It lends credence to the formal reports and provides an indication of potential problems much earlier than does a month-end statement of expenditures.

Several types of cost/performance measurement were applied by the QSRA project office at Ames. The weekly and monthly cost reports were carefully checked for the obvious clues to cost and schedule problems. Fortunately, there were few of any significance to be found. Occasionally an overbudget situation developed in a particular WBS element. Examination of the related schedule chart, engineering release performance curve, or manufacturing earned value data usually showed that it was because work was being accomplished ahead of schedule. When the work accomplished appeared to be consistent with the man-hours expended, no action was taken beyond a discussion of the situation with the NASA resident manager or the contractor.

When the work accomplished was less than the effort expended, or when both cost and schedule performance were inadequate, an impact analysis was

made. This consisted of an examination of both the budget and schedule for that WBS element. If the total budget was small, a 10% or 20% cost overrun would not be of great significance to the total program. Since on the QSRA program these were always offset by underbudget performance in other areas, they were noted for future observation but the "panic button" was not pushed. It is to be expected that some WBS elements will overrun and some will underrun on any program. This occurs, in part, because the original budgets are established early in the program when there are many unknowns and therefore may not accurately reflect the required effort in different areas, and, in part, because of the many factors which affect the actual performance.

The performance discrepancies of greatest concern were the schedule slips in areas affecting other activities or WBS elements. Schedule performance, per se, was of the *lowest* priority on the QSRA program (i.e., program cost or aircraft performance and safety was never to be compromised to meet a schedule). On the other hand, a delay on one relatively low-budget item (engineering release or manufactured part) can hold up other major activities, resulting in a significant reduction in overall productivity. Both Boeing and NASA project management were very conscious of this and monitored the milestone schedules closely. During the contractor functional organizations' weekly meetings, the effects of anticipated and actual late completions were evaluated, and "workaround" solutions were presented at management status meetings.

The contractor's management reserve was monitored carefully by the Ames project office, since it gives early warning of deviations from plan. Two values of management reserve were reported by the contractor, as indicated on figure 8. One was based on the internal budget and represented the unallocated contract funds held in reserve by the program director. The other reserve value was based on the WBS managers' estimates at completion for each WBS and represented the outlook at the "working level." Typically, the latter value is optimistic since people are either slow to recognize or hesitant to admit to problems in their areas of responsibility. On the QSRA, however, these estimates were quite realistic, and often conservative.

The management reserve was sometimes distorted when budgets were allocated for work authorized by contract change order but not yet definitized. Fluctuations in the mid 1978 time period reflect this (fig. 8). In such cases the reserve was replenished after the contract modifications were negotiated.

Also shown on figure 8 is the hypothetical depletion of the reserve which would occur if each WBS activity expended the funding level negotiated into the contract. The initial management reserve was created by reducing the budget for each WBS element by 10% from the contract value. If the cost of each activity had been estimated exactly, each budget would overrun by the ratio 10/9 and the reserve would be depleted in accordance with the total projected spending rate as shown. While no one expected the reserve to be depleted in precisely that fashion, the changing value of the actual management reserve, relative to that hypothetical depletion rate, was considered by the NASA project management to be an important measure of the

financial health of the contract. This was particularly true during the early months of the program when design changes, including cost saving changes, were occuring and manpower levels were building up. Good cost performance reflected by the consistently favorable management reserve during the course of the program provided an increasing degree of confidence that a cost underrun might be realized.

CONCLUSIONS AND RECOMMENDATIONS

The objective of a cost and schedule management system is to help project managers to meet program objectives with available resources. To meet this objective the system must accurately report actual expenditures and accomplishments in each WBS element. It should provide early detection of problems and help support development of cost-effective solutions. It should also foster cost consciousness among functional managers and facilitate performance measurement by top management. The suitability of competing contractors' cost management systems should be considered in the source selection process.

The system used by Boeing on the QSRA contract met the objectives admirably. It was adapted from existing systems of work authorization and cost accumulation, and hence its maintenance did not impose a financial burden on the contract. Yet the information available on a weekly and monthly basis was adequate for cost and schedule surveillance and program planning by both contractor and government project management.

The information provided in lieu of the 533P report was especially useful in trend analysis and in measuring cost and schedule performance. This type of information may not be adequate for all programs, and may not even be available in many instances. Nevertheless, government project managers should review alternate financial reports and consider accepting reports based on the contractor's internal cost and schedule management system whenever practical.

The informal cost and schedule performance measurement available through the NASA resident office proved very effective for the QSRA Project. Use of a resident office is recommended for all programs with a large budget or significant advance in the state of the art. Information is available sooner and is probably more candid than could be expected in formal written financial reports. The nature and sources of problems are identified in detail, and the preferred solution can be communicated to the contractor without delay.

REFERENCES

1. Diehl, James J.: Application of a Cost/Performance Measurement System on a Research Aircraft Project. NASA TM-78498, June 1978.

2. Procedures of Contractor Reporting of Correlated Cost and Performance Data. NASA NHB 9501.2A, October 1971.

WBS LEVEL

1	2	3	4

- QSRA PROGRAM
  - ANALYSIS
    - Aerodynamics
    - Propulsion
    - Structures
    - Systems
    - Flight Controls
    - Weights
    - Noise
    - Analysis, General
  - AIRPLANE STRUCTURE
    - Wing
      - Leading Edge
      - Wing Box
      - Trailing Edge
    - Body
    - Nacelle
    - Landing Gear
    - Empennage
    - Receivals and Layup
    - Airplane Structure, General
  - AIRPLANE SYSTEMS
    - Electrical/Electronics
    - Personnel/Cargo
    - Flight Controls
      - Electrical
      - Mechanical
    - ECS/Pneumatics
    - Propulsion
      - Engine Buildup
      - Fuel System
    - Hydraulics
    - Airplane Systems, General
  - TESTING
    - Mockup
    - Simulation
    - BLC System Calibration
    - Systems Functional Test
    - Ground Test
    - Contractor Flgiht Test
    - Support to NASA Flight Test
  - PRODUCT ASSURANCE
    - Quality Assurance
    - Safety, Reliability, Maintainability
  - PROGRAM MANAGEMENT
    - Contractor Management
    - Engine Support
  - SPARES & GFE REPAIR

Figure 1.— QSRA work breakdown structure.

Report		WBS Level
533M/533Q		1, 2, 3, 4
533P		1, 2
533P Equivalent		3, 4
	° Milestone Schedules	
	° Engineering Releases	
	° Manufacturing Earned Value	
	° Manpower	
	° Total Cost	
Supplemental Data		
	° Budget Visibility Report	1, 2, 3
	° Labor & Overhead Rates	1

Figure 2.— Monthly financial reporting.

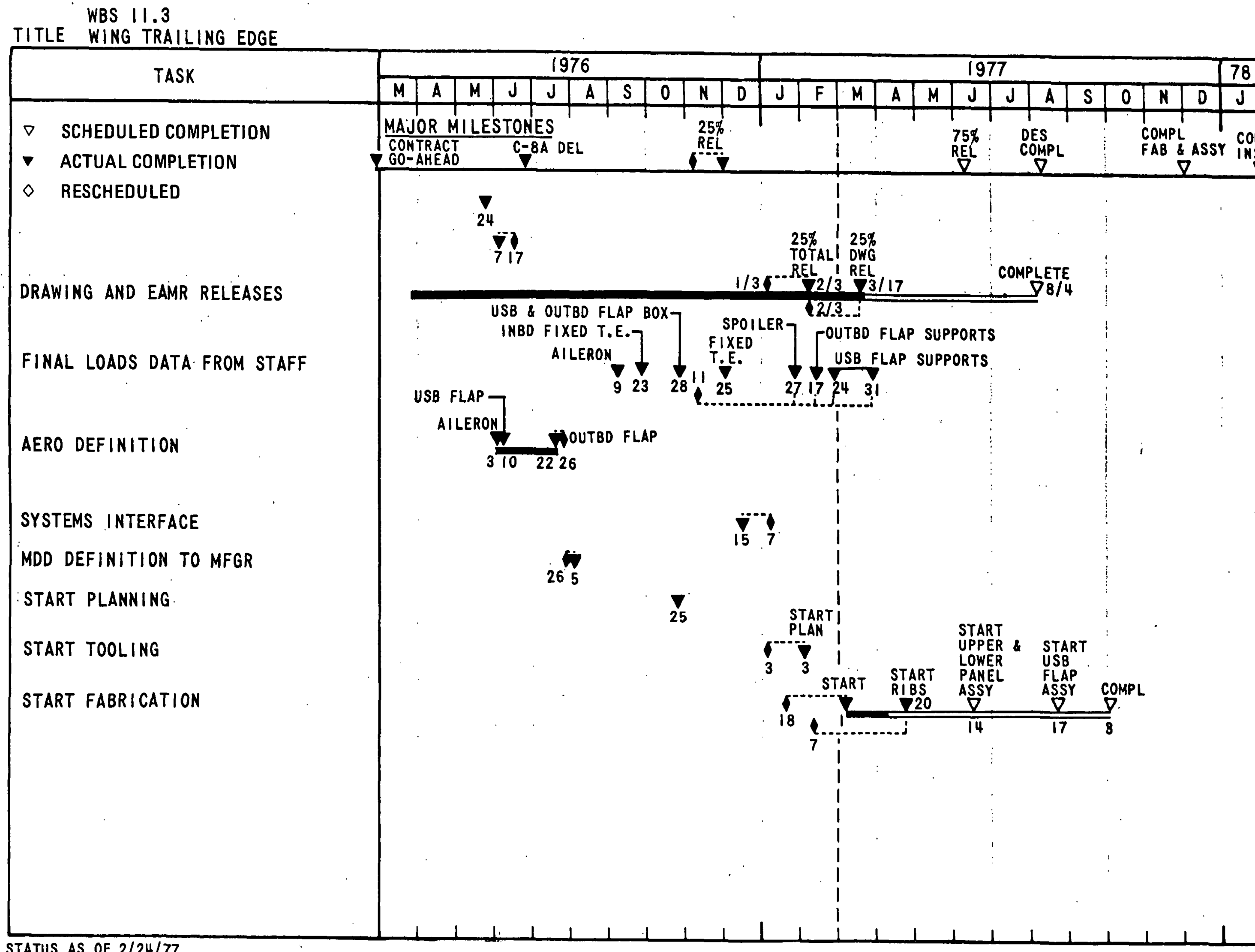

Figure 3.— Milestone schedule - wing trailing edge.

WBS 11.3

TITLE WING TRAILING EDGE

MO/YR	CUM RELEASES COM	ACT	AHD	BHD	VAR
3/76					
4/76					
5/76					
6/76	0	2	2	0	+ 2
7/76	0	2	2	0	+ 2
8/76	2	2	0	0	0
9/76	2	2	0	0	0
10/76	4	4	0	0	0
11/76	7	8	1	0	+ 1
12/76	10	13	3	0	+ 3
1/77	13	16	3	0	+ 3
2/77	15	27	12	0	+12
3/77	23				
4/77	31				
5/77	37				
6/77	44				
7/77	50				
8/77	52				
9/77					
10/77					
11/77					
12/77					
1/78					

W/E	CUM CURRENT MONTH COM	ACT	AHD	BHD	VAR
2/3	14	20	6	0	+ 6
2/10	14	24	10	0	+10
2/17	14	24	10	0	+10
2/24	15	27	12	0	+12

STATUS AS OF 2/24/77

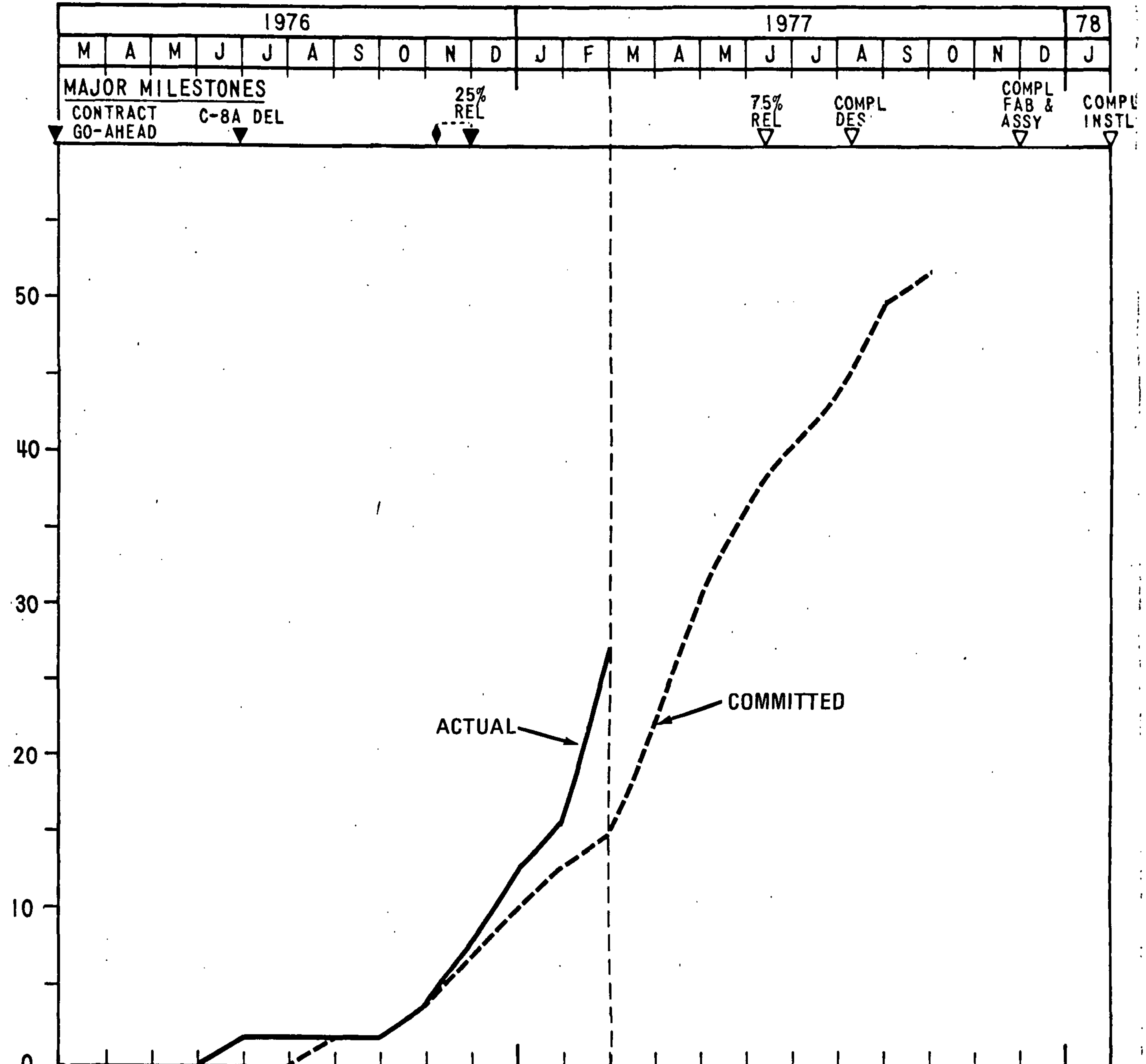

Figure 4.— Engineering releases - wing trailing edge.

WBS 11.3

TITLE TRAILING EDGE

MO/YR	CUM MANHOURS BUDGET	EARNED	ACTUAL
3/76			
4/76			
5/76			
6/76			
7/76			
8/76			
9/76			
10/76			
11/76		1	1
12/76		98	146
1/77		1101	433
2/77	1346	2556	1052
3/77	2491		
4/77	3773		
5/77	5443		
6/77	10788		
7/77	15950		
8/77	21402		
9/77	25500		
10/77	26689		
11/77			
12/77			
1/78			

STATUS AS OF 2-24-77

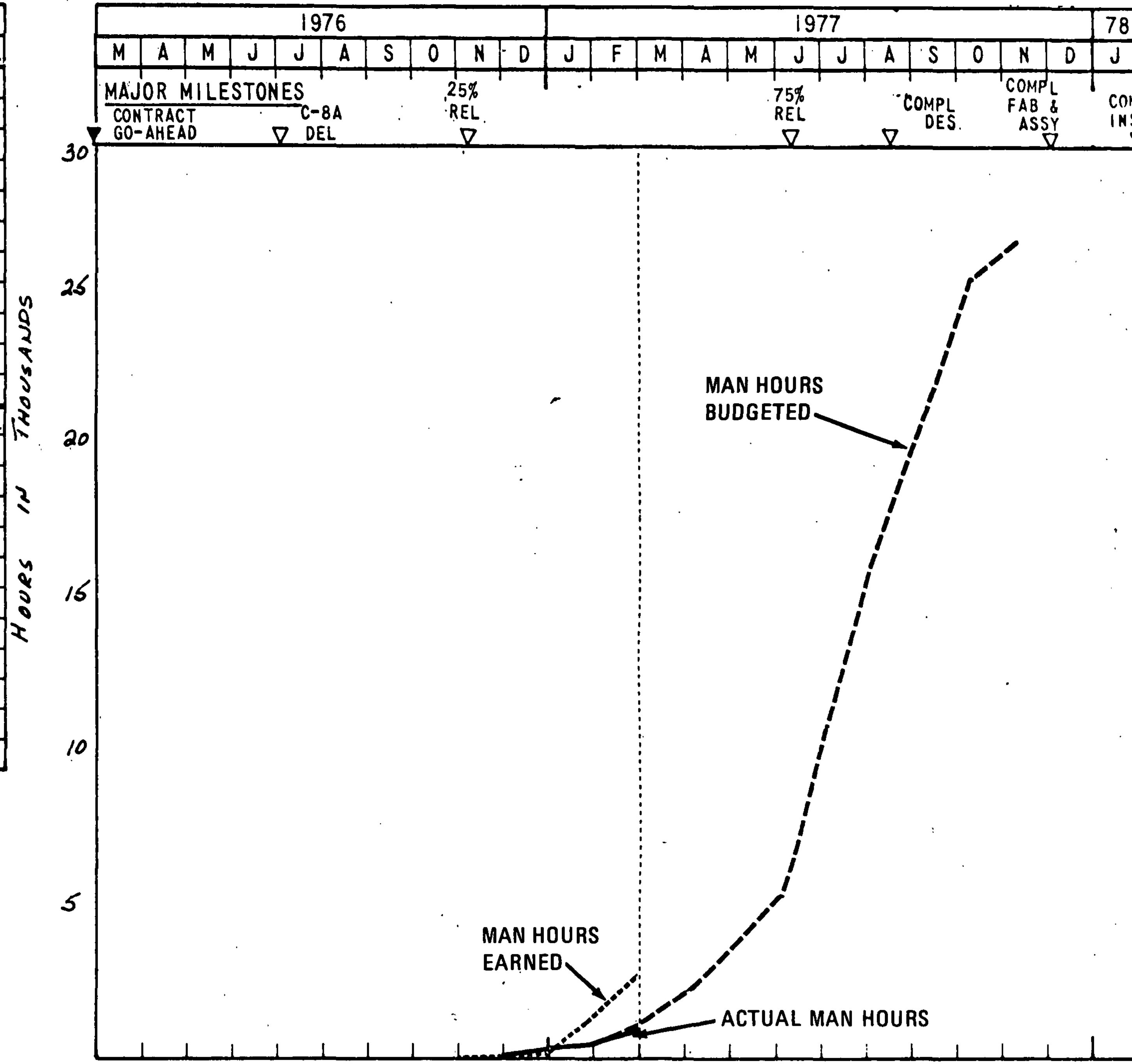

Figure 5.— Manufacturing earned value - wing trailing edge.

WBS 11.3
TITLE WING TRAILING EDGE

MO/YR	MANPOWER BUDGET		MANPOWER ACTUAL		MANPOWER VAR	
	E	O	E	O	E	O
3/76			0.9			
4/76			1.7			
5/76			2.4			
6/76			3.2			
7/76			2.5			
8/76			2.8			
9/76	3.8		4.2		+0.4	
10/76	3.8		3.6		-0.2	
11/76	4.8		5.3		+0.5	
12/76	5.8	1.0	5.9	1.0	+0.1	0
1/77	7.1	2.0	5.0	2.0	-2.1	0
2/77	7.8	6.0	5.2	4.0	-2.6	-2.0
3/77	7.9	6.1				
4/77	8.0	8.7				
5/77	6.8	11.3				
6/77	4.8	31.3				
7/77	3.8	40.0				
8/77		40.4				
9/77		23.7				
10/77		8.1				
11/77						
12/77						
1/78						

W/E	CURRENT MONTH BUDGET		CURRENT MONTH ACTUAL		CURRENT MONTH VAR	
	E	O	E	O	E	O
2/3	7.8	6.0	5.5	6.0	-2.3	0
2/10	7.8	6.0	6.1	5.3	-1.7	-0.7
2/17	7.8	6.0	5.1	3.6	-2.7	-2.4
2/24	7.8	6.0	4.1	1.2	-3.7	-4.8

STATUS AS OF 2/24/77

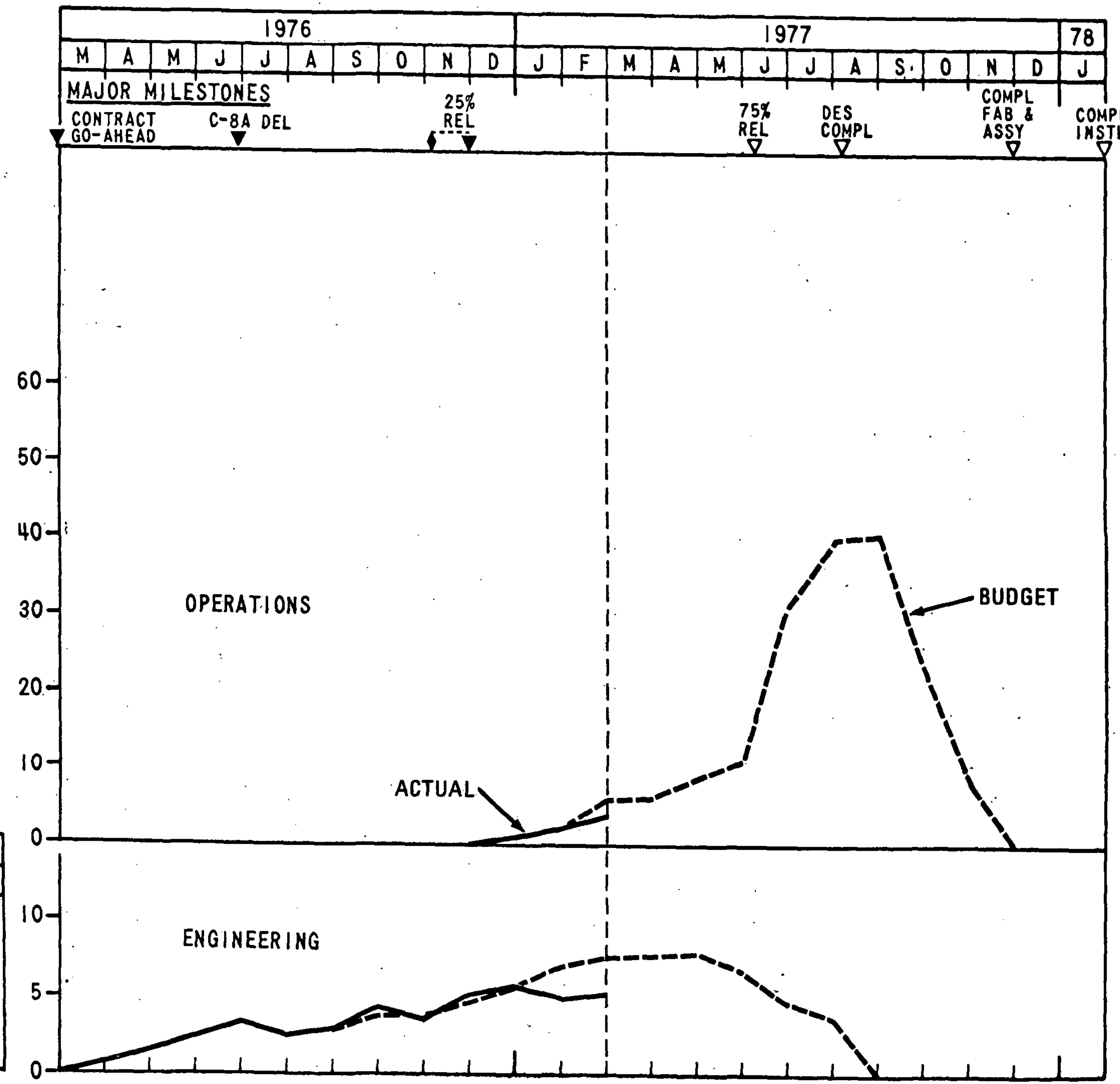

Figure 6.— Manpower - wing trailing edge.

WBS 11.3
TITLE TRAILING EDGE

COST ELEMENT VARIANCE		+* −
CUM MANHOURS		
ENGR		
MFG		
CUM DOLLARS		
TOTAL		
LABOR		
ENGR		
DIRECT		
FRINGE		
OVERHEAD		
MFG		
DIRECT		
FRINGE		
OVERHEAD		
RATES		
ENGR		
DIRECT		
FRINGE		
OVERHEAD		
MFG		
DIRECT		
FRINGE		
MFG O.H.		
FAB DIV O.H.		
OTHER O.H.		
NON-LABOR		
COMPUTING		
SUB CONT		
P.E.		
MATERIAL		
TRAVEL		
OTHER		

* LEGEND
+ OVER BUDGET — UNDER BUDGET

STATUS AS OF 2/24/77

CURRENT MONTH
CUM $'s IN 000's

W/E	BUDGET	ACTUAL	VAR
PREV MO	177.9	176.6	-1.3
2/10	206.6	200.9	-5.7
2/24	236.5	217.4	-19.1

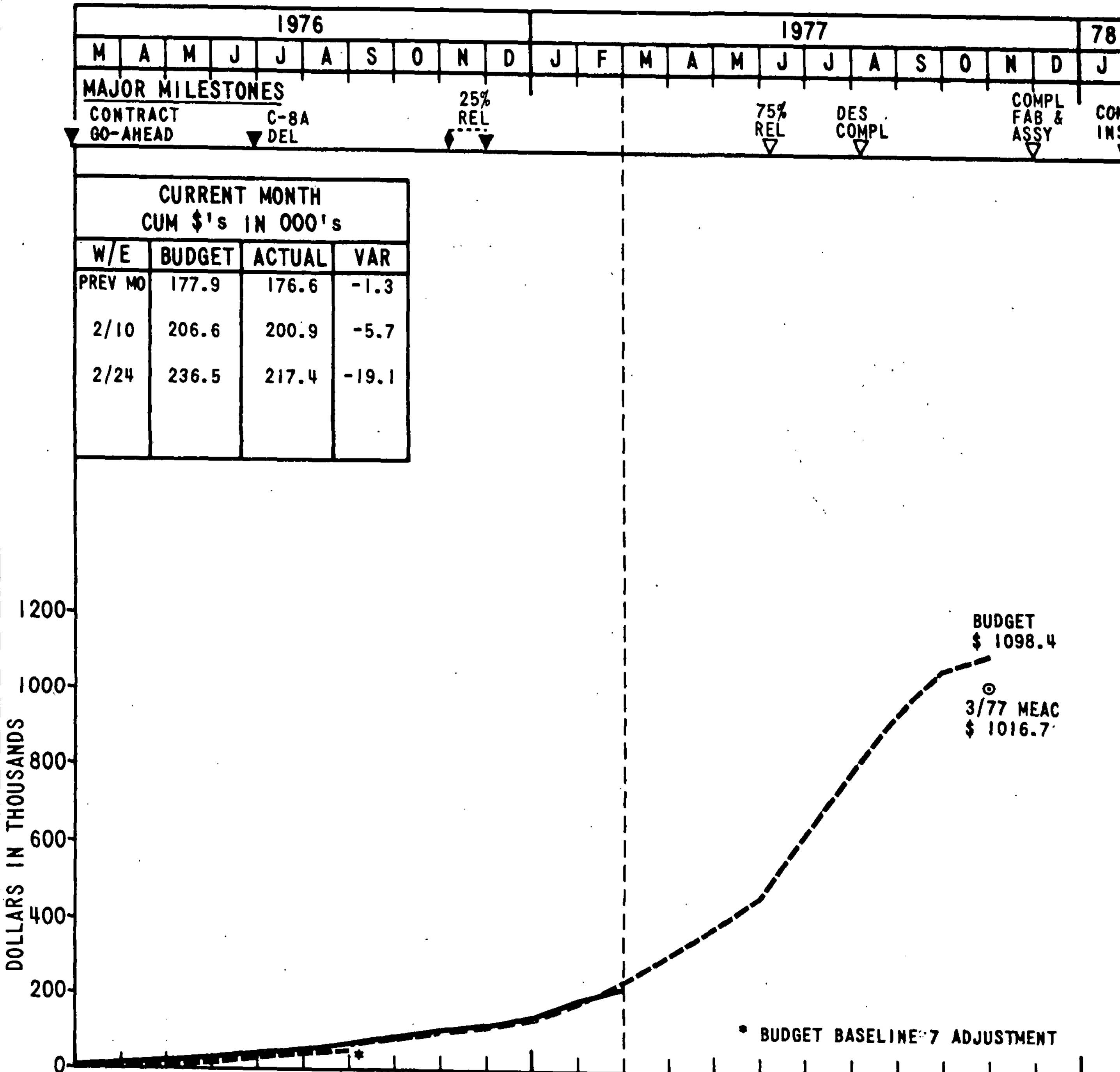

Figure 7.— Total cost - wing trailing edge.

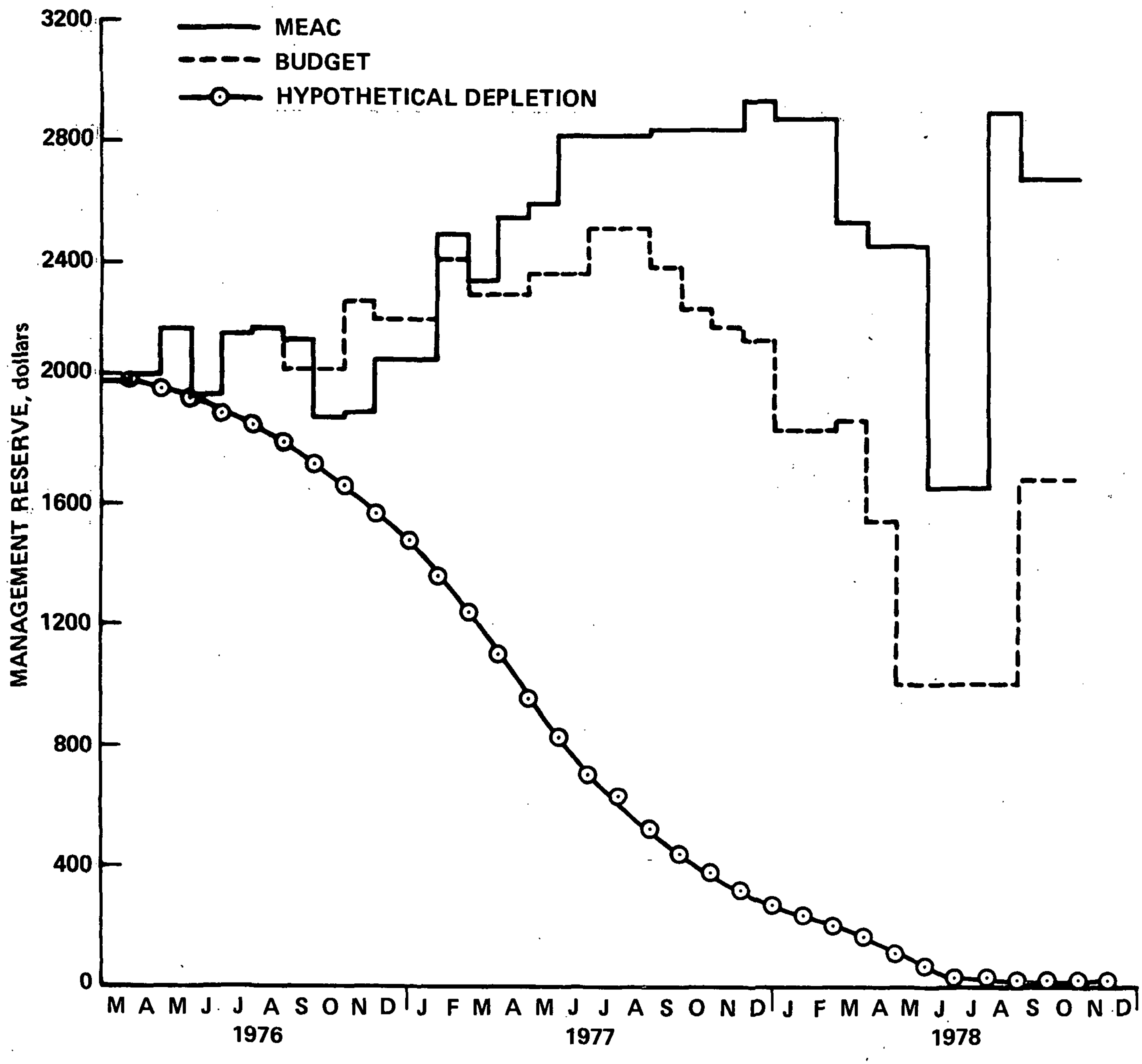

Figure 8.— QSRA management reserve.

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16. Abstract

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